Chapter 24

- Microbiology: A Systems Approach

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1st Edition

Chapter 24

Topics

- Ecology
- Applied Microbiology and Biotechnology

Ecology

- Ecosystem organization
- Energy and nutrient flow
- Recycling of bioelements
- Atmospheric cycles
- Sedimentary cycles
- Soil microbiology
- Aquatic microbiology

Ecology organization

- Microbial ecology – the study of microbes in their natural habitats
- Levels of ecology

Levels of ecology

- Biosphere
  - Terrestrial – biomes
  - Aquatic
- Ecosystem
  - Hydrosphere
  - Lithosphere
  - Atmosphere
- Communities
- Populations
- Habitats
- Niche

The different levels of organization in an ecosystem, which ranges from the biosphere to the individual organism.

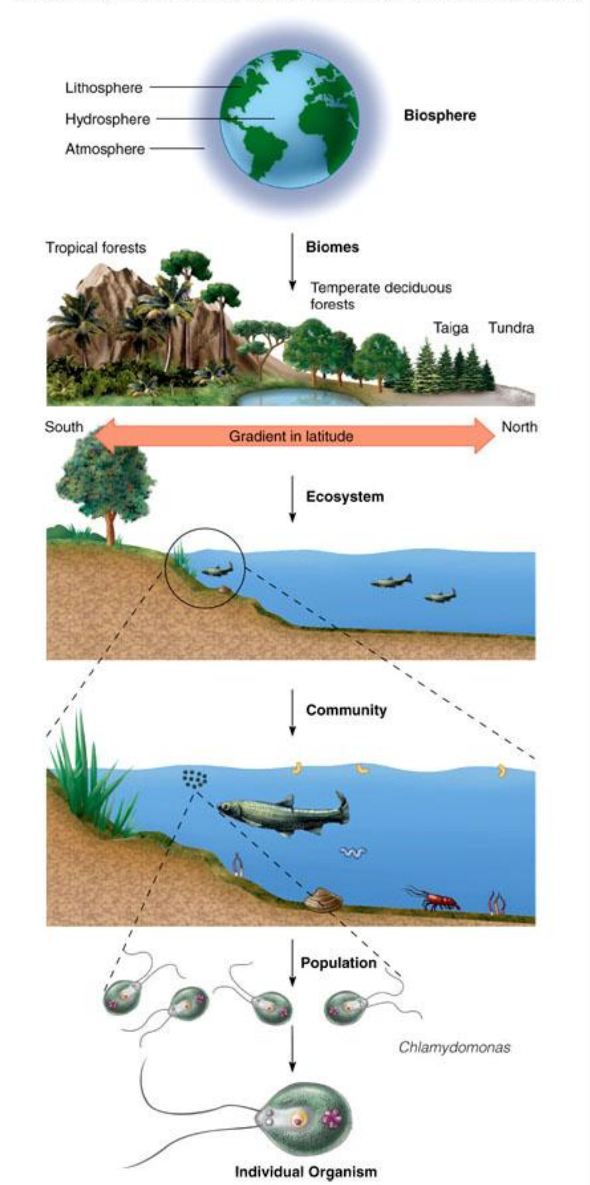


Fig. 24.2 Levels of organization in an ecosystem

Energy and nutrient flow

- Food chain
- Producers
- Consumers
- Decomposers
- Limitation
- Ecological interactions

Food chain

- Energy pyramid
  - Begins with a large amount of usable energy and ends with a smaller amount of usable energy
- Trophic (feeding) levels
  - The number of organisms that are producers, consumers and decomposers

An example of the trophic and energy pyramid.

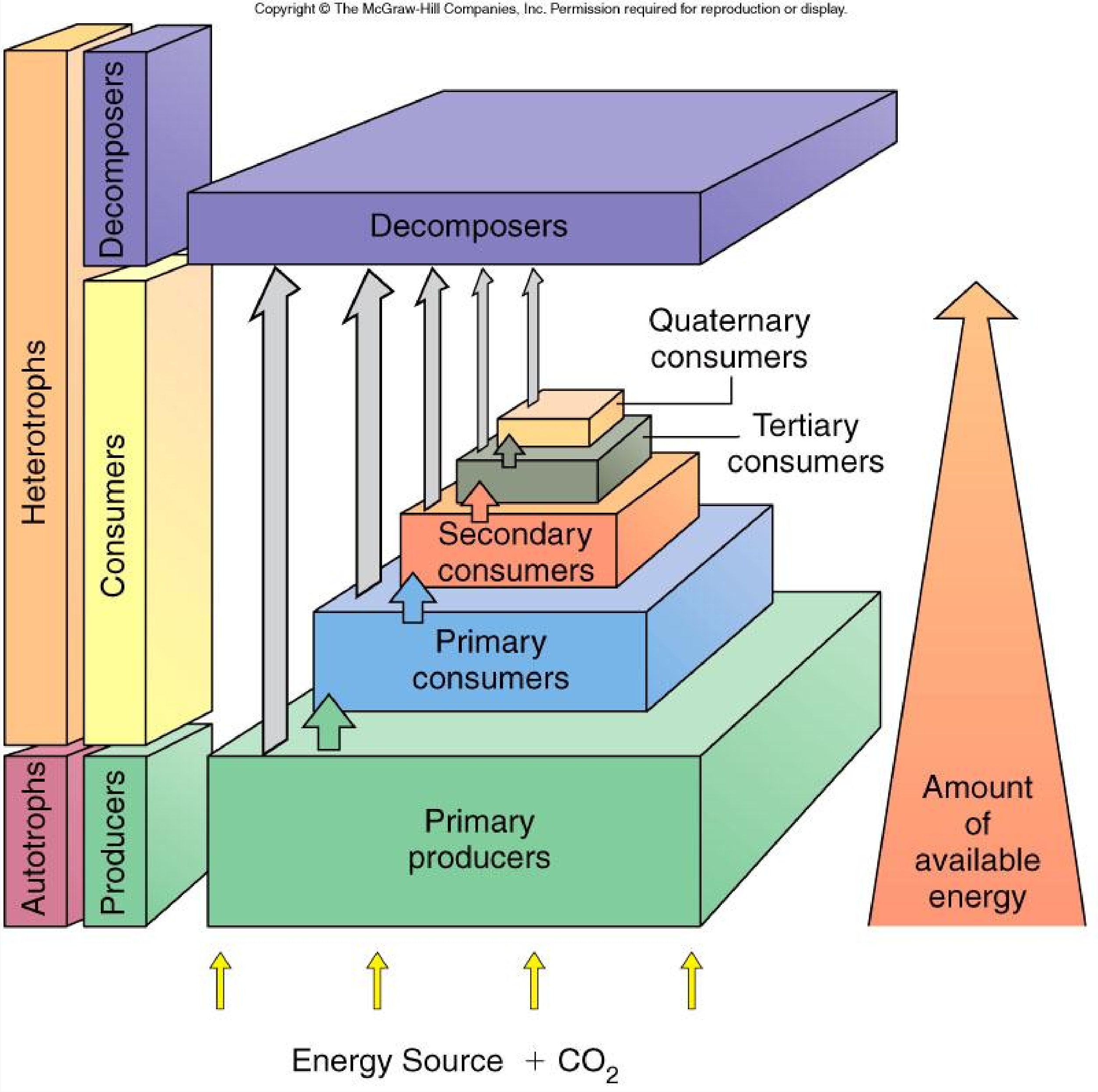


Fig. 24.3 A trophic and energy pyramid.

The roles, description of their activities, and types of microorganisms involved in the ecosystem.

TABLE 24.1 The Major Roles of Microorganisms in Ecosystems

Role	Description of Activity	Examples of Microorganisms Involved
Primary producers	Photosynthesis	Algae, cyanobacteria, sulfur bacteria
	Chemosynthesis	Chemolithotrophic bacteria in thermal vents
Consumers	Predation	Free-living protozoa that feed on algae and bacteria; some fungi that prey upon nematodes
Decomposers	Degradation of plant and animal matter and wastes	Soil saprobes (primarily bacteria and fungi) that degrade cellulose, lignin, and other complex macromolecules
	Mineralization of organic nutrients	Soil bacteria that reduce organic compounds to inorganic compounds such as CO_2 and minerals
Cycling agents for biogeochemical cycles	Recycling compounds containing carbon, nitrogen, phosphorus, sulfur	Specialized bacteria that transform elements into different chemical compounds to keep them cycling from the biotic to the abiotic and back to the biotic phases of the biosphere
Parasites	Living and feeding on hosts	Viruses, bacteria, protozoa, fungi, and worms that play a role in population control

Table 24.1 The major roles of microorganisms in ecosystems.

Producer

- Fundamental energy source
- Drives the trophic pyramid
- Autotrophs - produce organic carbon compounds by fixing inorganic carbon
- Photosynthetic organisms
  - Plants
  - Cyanobacteria
- Lithotrophs

Consumers

- Feed on other living organisms
- Obtain energy from organic substrate bonds (break bonds=release energy)
- Ex. Animals, protozoa, some bacteria and fungi
- Several levels
  - Primary, secondary, tertiary and quaternary consumers

A simple example of the different levels of a consumer.

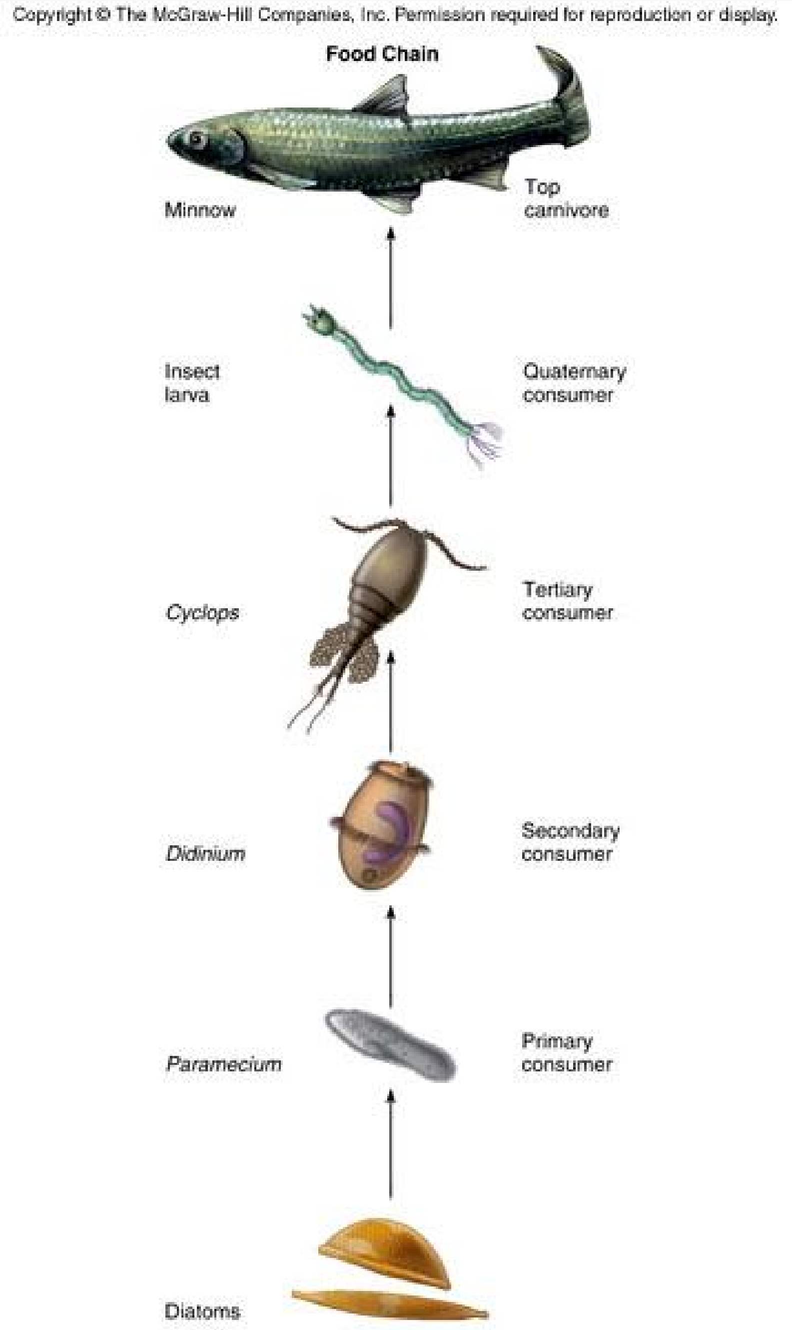


Fig. 24.4 Food chain

Decomposer

- Saprobes - inhabit all levels of the food pyramid
- Primarily bacteria
- Reduce organic matter into inorganic minerals and gases
- Mineralization - cycled decomposed material back into the ecosystem

Trophic patterns can be complex, as many producers and composers are involved.

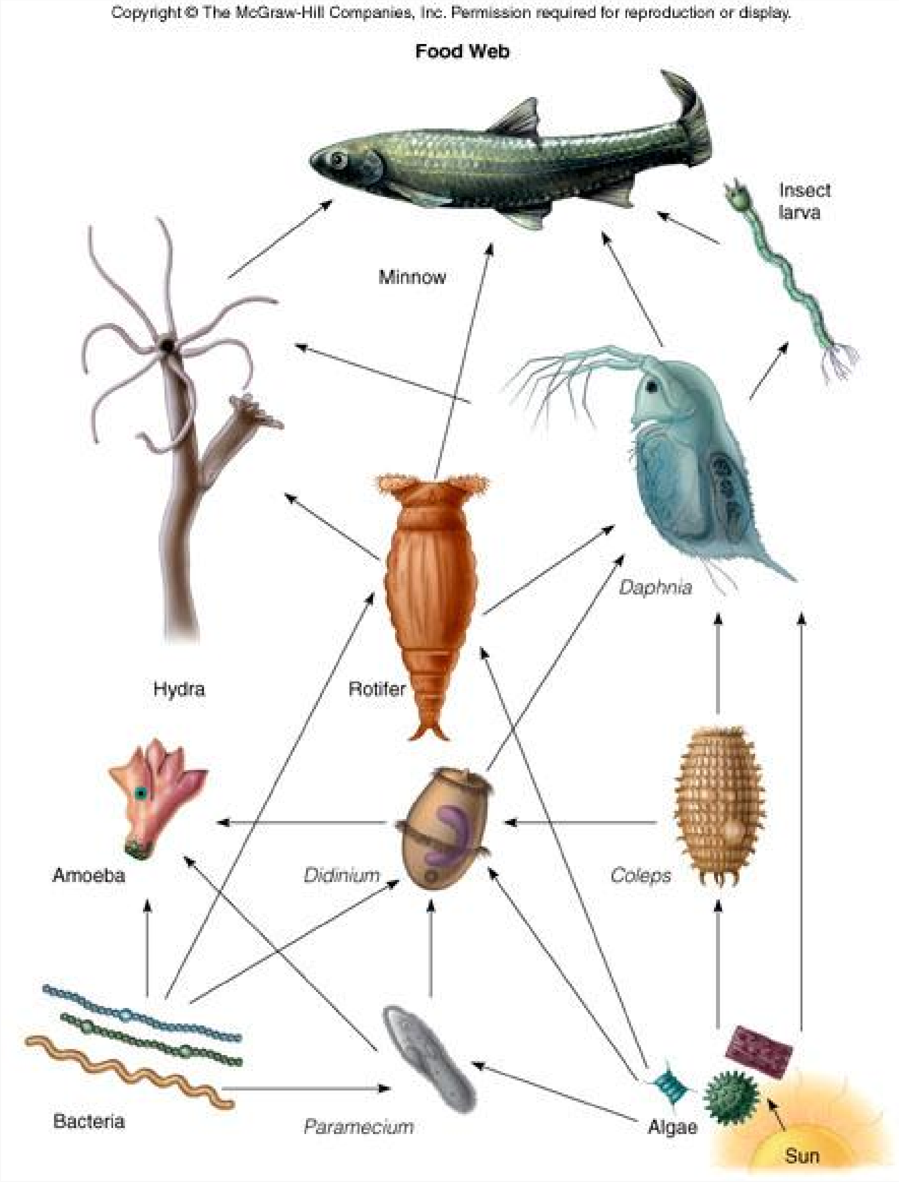


Fig. 24.5 Food web

Limitation

- Energy is not cycled
- As energy is transferred from producer to consumer, large amounts of energy are lost in the form of heat
- Amount of energy available decreases at each successive trophic level
- Fewer individuals can be supported by remaining available energy

Ecological interactions

- Commensalism
- Co-metabolism
- Synergism
- Parasitism
- Competition
- Predator
- Scavengers

Recycling of bioelements

- Bioelements – carbon, nitrogen, sulfur, phosphorus, oxygen, iron, and essential building blocks
- Biogeochemical cycles – recycling of essential elements and essential building blocks through biotic and abiotic environments

Atmospheric cycles

- Carbon cycles
- Photosynthesis
- Nitrogen cycle

Soil Microbiology

- Dynamic ecosystem
- Lithosphere - interactions between geologic, chemical, and biological factors
- Humus
- Rhizosphere - synergism (plant and biofilm)
- Mycorrhizae – synergism (plant and fungi)
- Top soil – supports nematodes, termites, earthworms as well as aerobic and anaerobic bacteria

A microhabitat can contain soil particles, bacteria, fungi, protozoa, nematodes, gas, and water.

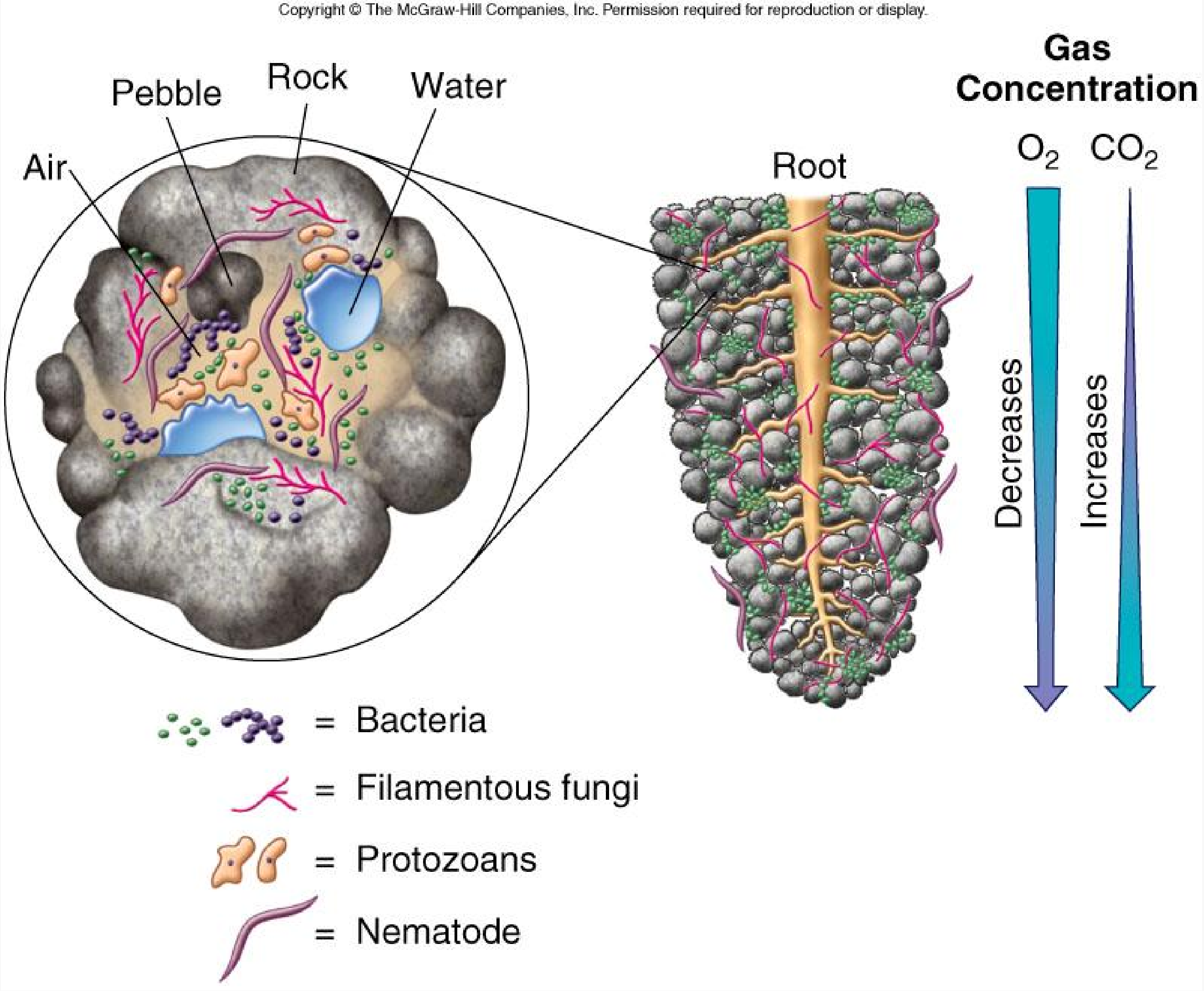


Fig. 24.12 The structure of the rhizophere and the Microhabitats that develop in response to soil particles

Mycorrhizae is a symbiotic association between fungi and plant roots, which helps the plant absorb water and minerals more efficiently.

Fig. 24.13 Mycorrhizae, symbiotic association between Fungi and plant roots

Aquatic microbiology

- Hydrolic cycle
- Marine environments
- Communities
- Water management

Two important mechanism of the hydrolic cycle involves plants releasing water through transpiration, and heterotrophs releasing water through respiration.

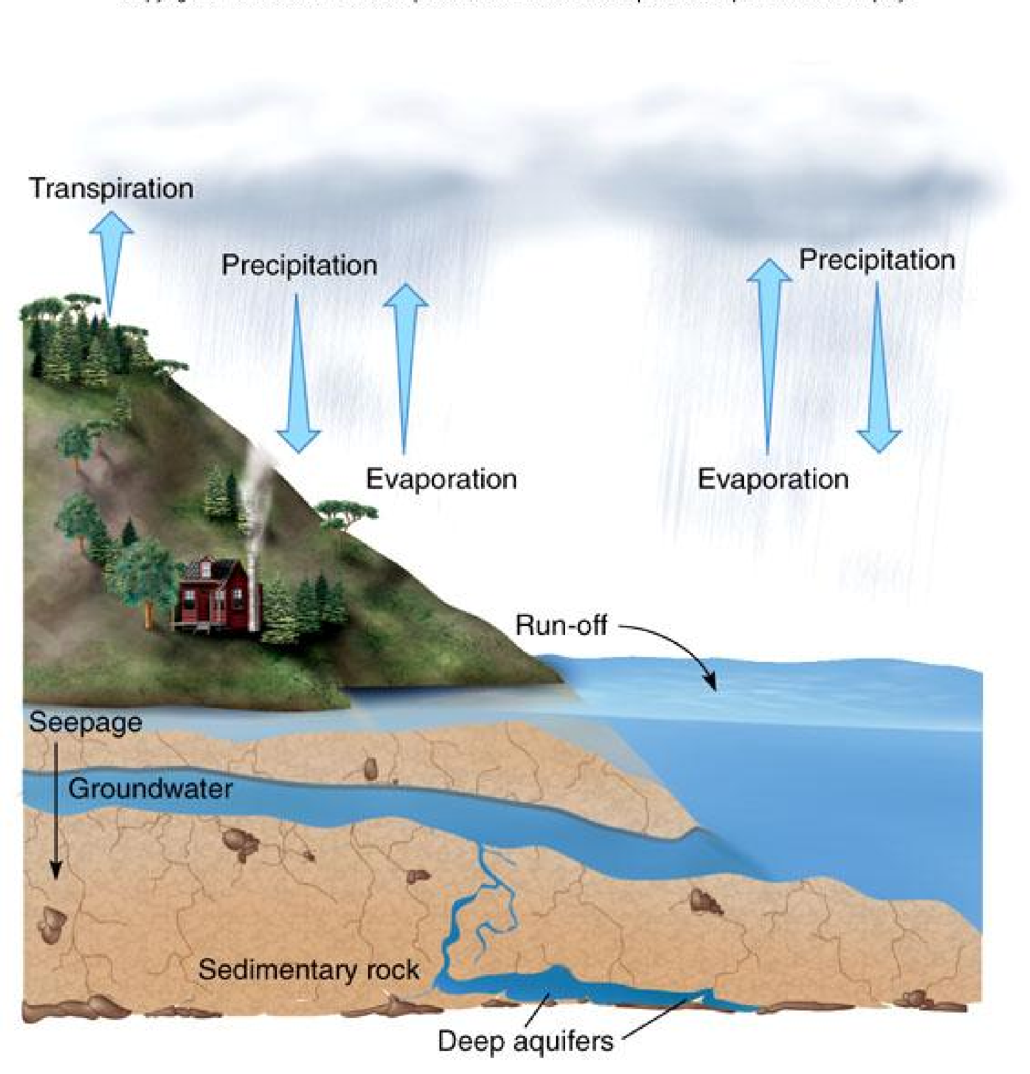


Fig. 24.14 The hydrolic cycle

The distribution of water on the earth's surface.

TABLE 24.2 Distribution of Water on Earth's Surface

Water Source	Water Volume, in Cubic Miles	Percent of Total Water
Oceans	317,000,000	97.24
Icecaps, glaciers	7,000,000	2.14
Groundwater	2,000,000	0.61
Freshwater lakes	30,000	0.009
Inland seas	25,000	0.008
Soil moisture	16,000	0.005
Atmosphere	3,100	0.001
Rivers	300	0.0001
		100

Source: U.S. Geological Survey.

Table 24.2 Distribution of water on earth's surface.

Marine environments

- Variable
  - Estuary (salinity, nutrients)
  - Mixing (tidal and wave action)
  - Temperature
  - Abyssal zone (hydrostatic pressure, lack sunlight, low temperature, oxygen poor, depth)

Communities

- Freshwater
- Plankton – provides nutrients for zooplankton
- Temperature strata
  - Epilimnion
  - Thermocline
  - Hypolimnion
- Upwelling – red tides
- Oligotrophic – low nutrient water
- Viruses present
- Eutrophication - bloom

The three strata in a lake vary in temperature and nutrient content, and mixing (upwelling) of the strata occurs seasonally.

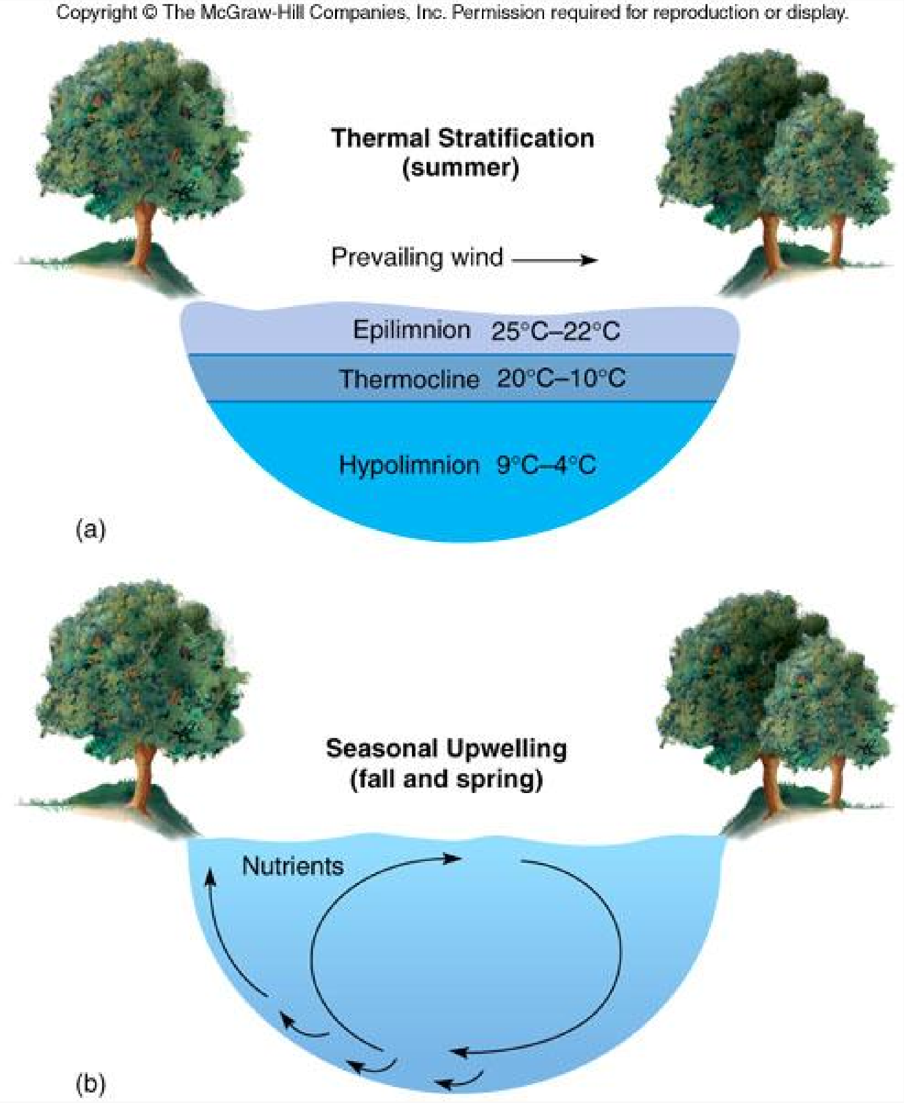


Fig. 24.15 Profiles of a lake.

Upwelling in the ocean can result in increased microbial activity of toxin-producing dinoflagellates, which causes red tides.

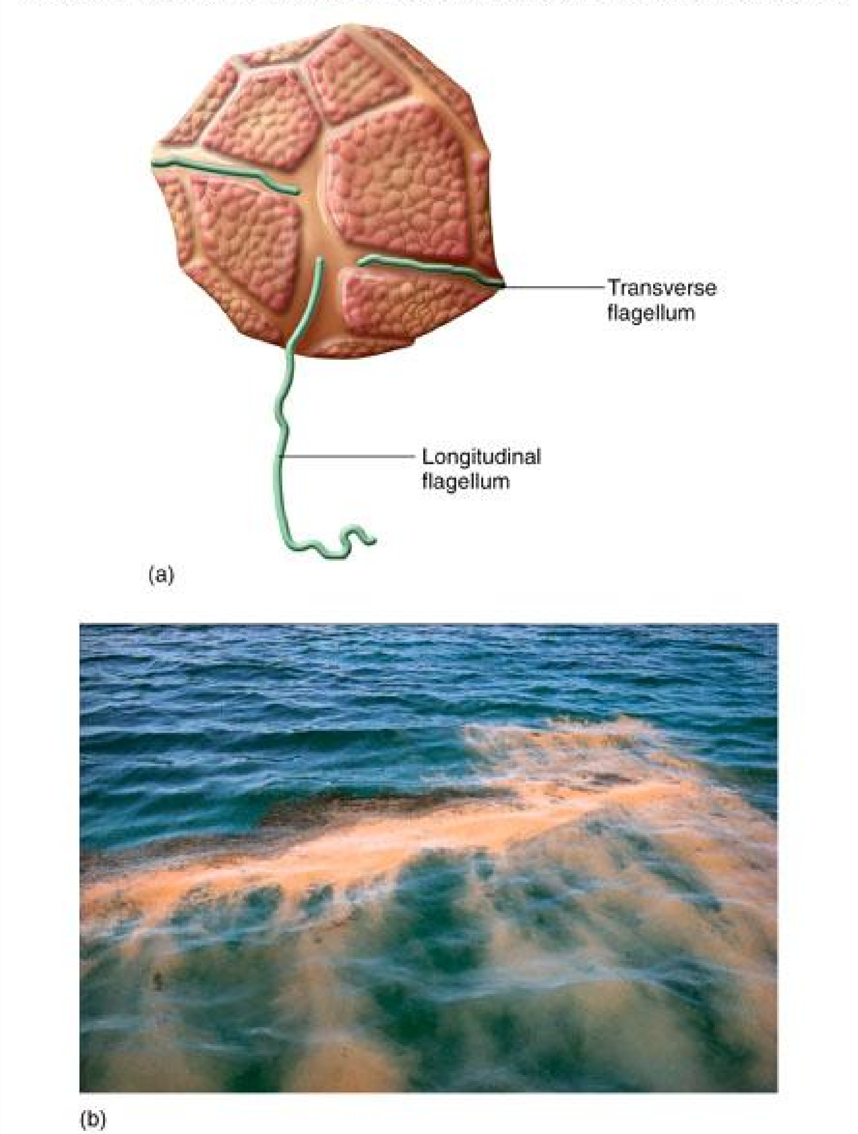


Fig. 24.16 Red tides.

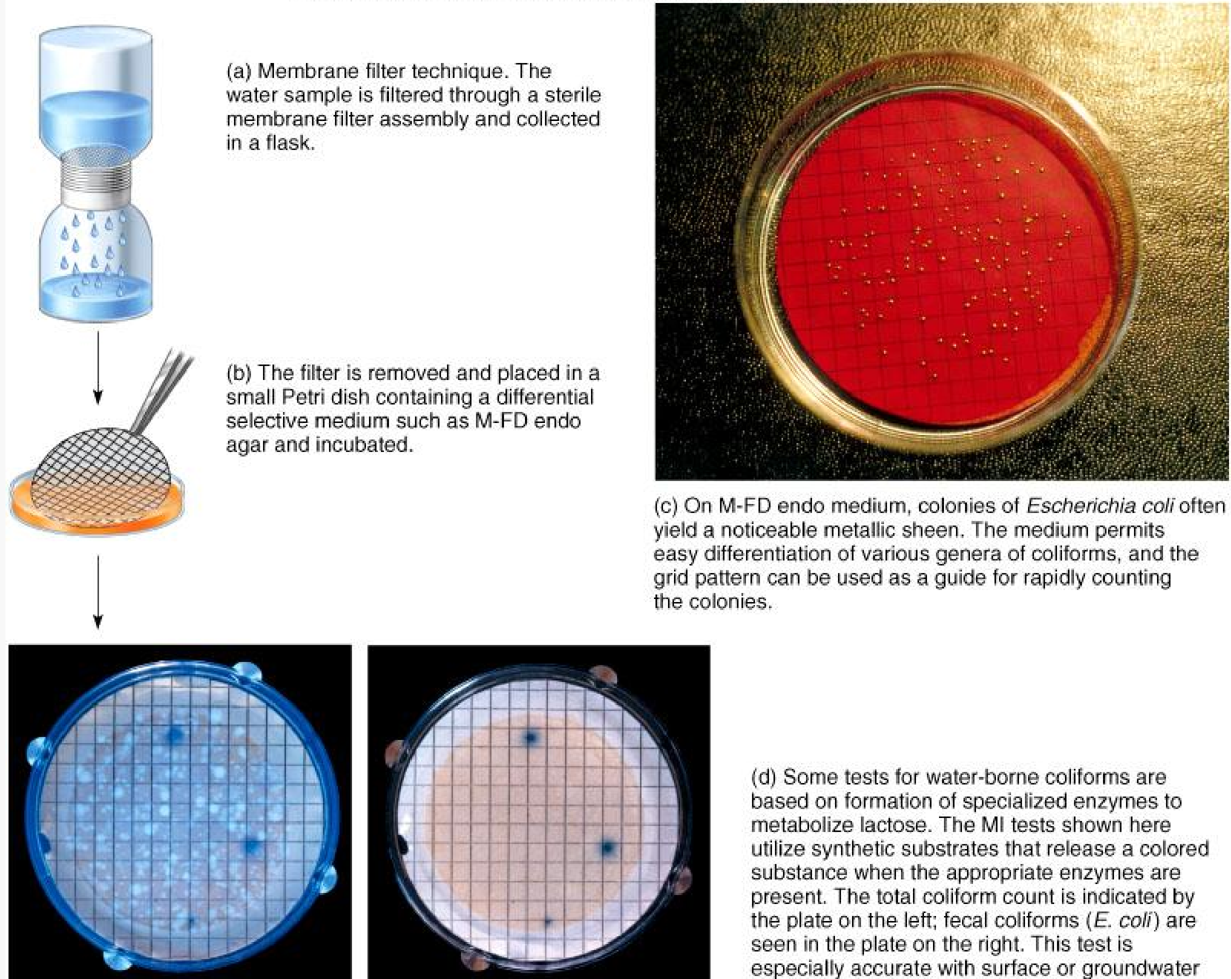
Excess nutrients and warm pond water can result in eutrophication or blooms, which is the heavy growth of algae resulting is oxygen depletion below the surface.

Fig. 24.17 Heavy surface growth of algae and cyanobacteria In a eutrophic pond.

Water management

- Indicator bacteria – coli forms
  - Standard plate count
  - Membrane filtration
  - Most probable number
- Water and sewage treatment

An example of the filter method, where visible colonies are observed as well as the presence of specific enzymes.



(a) Membrane filter technique. The water sample is filtered through a sterile membrane filter assembly and collected in a flask.

(b) The filter is removed and placed in a small Petri dish containing a differential selective medium such as M-FD endo agar and incubated.

(c) On M-FD endo medium, colonies of *Escherichia coli* often yield a noticeable metallic sheen. The medium permits easy differentiation of various genera of coliforms, and the grid pattern can be used as a guide for rapidly counting the colonies.

(d) Some tests for water-borne coliforms are based on formation of specialized enzymes to metabolize lactose. The MI tests shown here utilize synthetic substrates that release a colored substance when the appropriate enzymes are present. The total coliform count is indicated by the plate on the left; fecal coliforms (*E. coli*) are seen in the plate on the right. This test is especially accurate with surface or groundwater samples.

Total coliforms fluoresce under a black light.

E. coli colonies are blue under natural light.

Fig. 24.18 Rapid methods of water analysis for coliform contamination.

Water and sewage treatment

- Water treatment
  - Rivers
  - Reservoirs
  - Wells (less stringent)
- Sewage treatment
  - Homes
  - Industry
  - Three stages
    - Second stage – anaerobic digester – methane gas

The steps involved in water treatment.

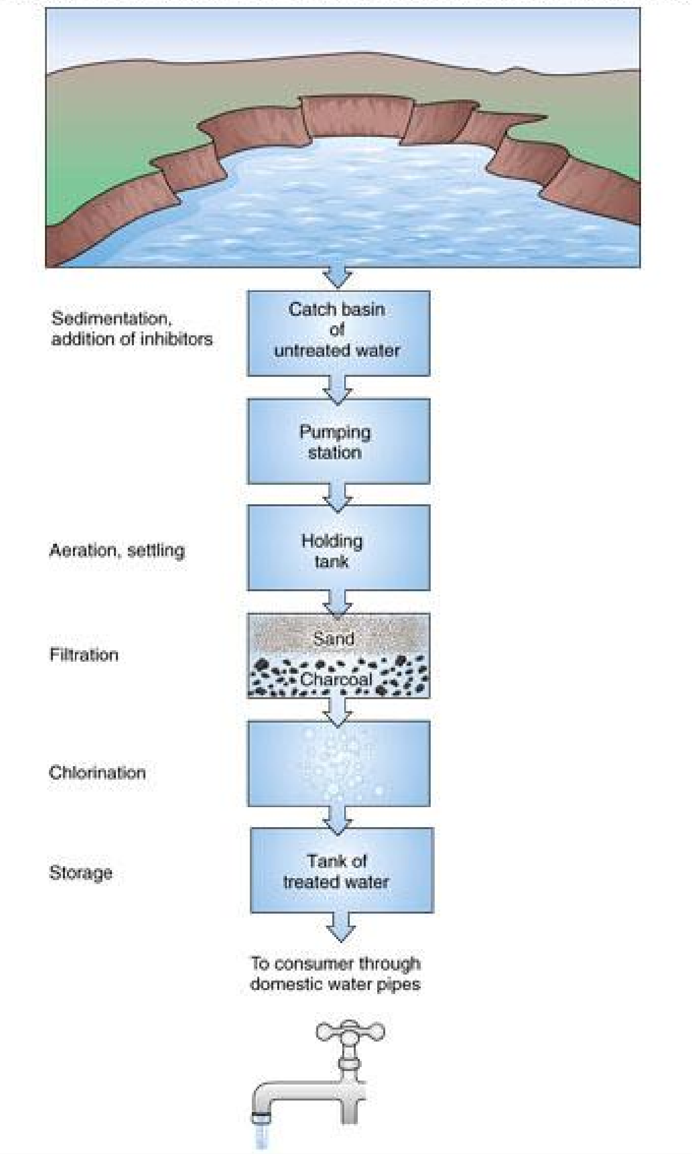


Fig. 24.19 The major steps in water purification as Carried out by a modern municipal treatment plant.

To remove all potential health hazards, sewage treatment requires three stages.

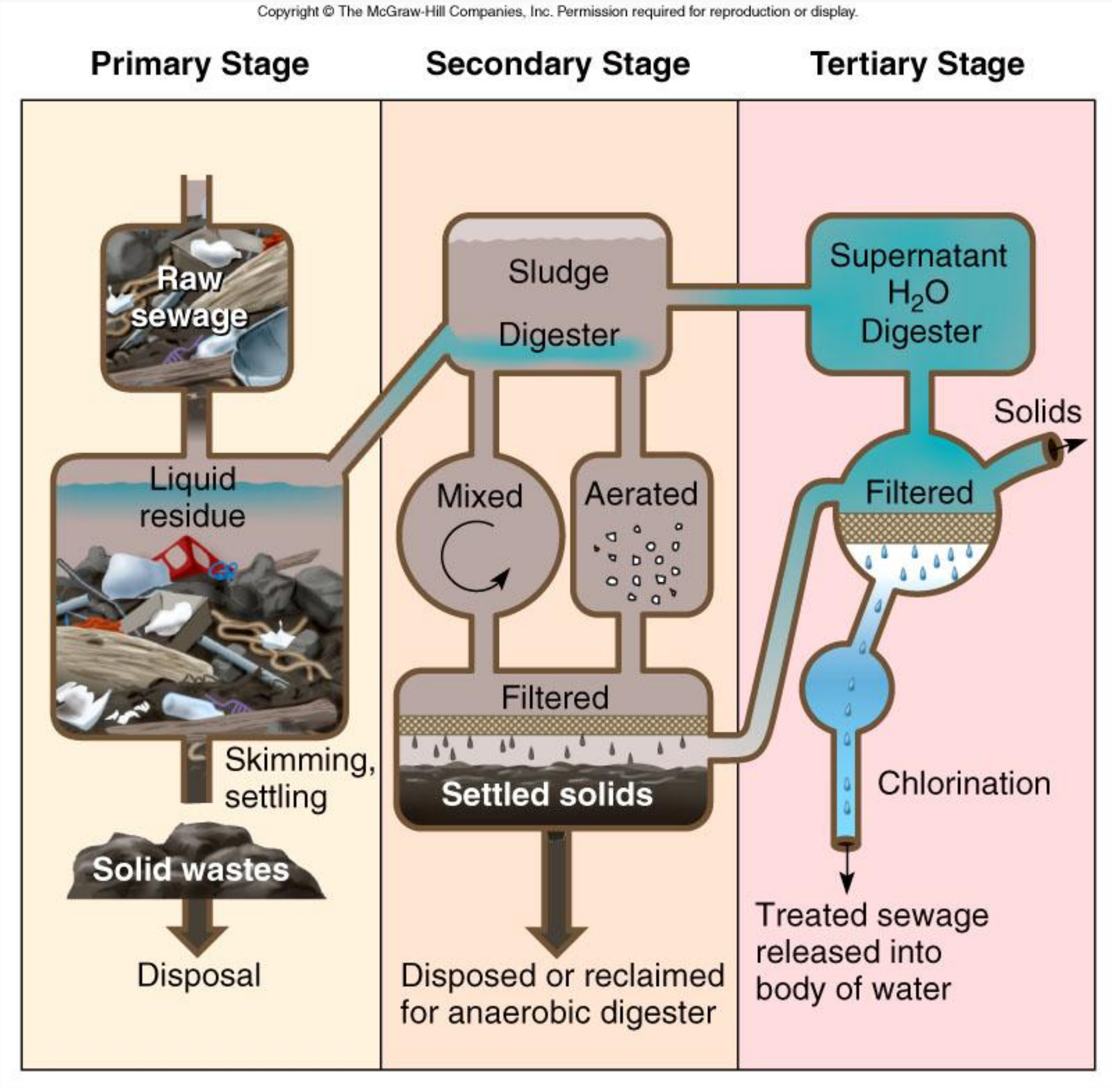


Fig. 24.20 The primary, secondary, and tertiary stages in Sewage treatment.

Large digester tanks are used in the primary and secondary stages.

(a)

(b)

Fig. 24.21 Treatment of sewage and wastewater.

Applied microbiology and biotechnology

- Food microbiology
- Industrial microbiology

Food microbiology

- Food fermentation
- Dairy products
- Microbes as food
- Food-borne diseases

Food fermentation

- Bread
- Beer
- Wine and liquors
- Others

Bread

- Baker's yeast
- Fermentation
  - Release carbon dioxide and water
  - Leavening
- Microbes breakdown flour proteins (gluten)
- Generates volatile organic acids and alcohols – imparts flavor and aroma

Beer

- Ethyl alcohol is produced from wort sugar
- Malting - nutrients from barley are made available to yeasts
- Mash – malt grain, which is supplemented with sugar and starch
- Wort – clear liquid rich in dissolved carbohydrates, obtained after mash mixing and heating
- Hops – dried scales of the female flower *Humulus lupulus*

Hops is boiled with wort in order to remove bitter acids and resins, as well as to provide the final flavor and aroma.

Fig. 24.22 Hops

Wine and liquors

- Wine
  - Must – juice of crushed fruit
  - Bloom – yeast on the surface of grapes
  - Alcohol content limits fermentation
- Liquors
  - Distill fermentation product to obtain higher alcohol content
- Other fermented plant products
  - Pickles, sauerkraut, vinegar

Dairy products

- Milk
  - Curd
  - Whey
- Cheese - curd
  - Soft
  - Ripening – infusion of microbes for further fermentation
    - semisoft and hard cheeses
- Yogurt

Different stages of milk fermentation, and the number and type microbes involved.

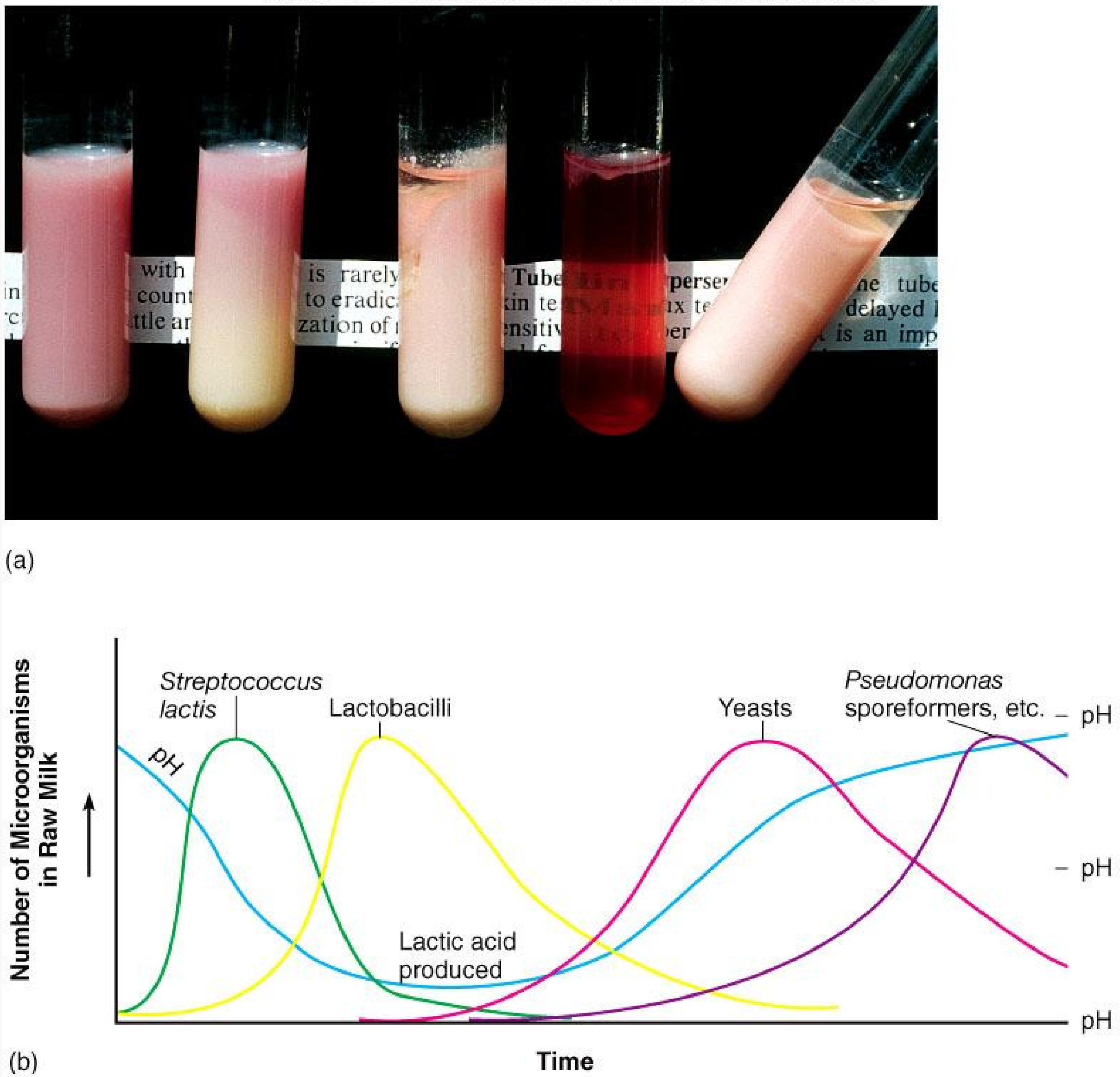


Fig. 24.24 Microbes at work in milk products.

An example of the curd cutting process in the making of cheese.

Fig. 24.25 Cheese making.

Microbes in food

- Microbes can supply protein, fat, and vitamins
- Yeast, bacteria and some algae are made into food
  - pellets
- Use the product of microbes
  - Single cell protein

Food-borne diseases

- Incidence
- Prevention

The Centers for Disease Control's (CDC) estimate of the incidence of food-borne illness in the United States.

TABLE 24.3	Estimated Incidence of Food-Borne Illness in the United States
Illnesses	76,000,000 cases
Hospitalizations	325,000 cases
Deaths	5,200 cases

Table 24.3 Estimated incidence of food-borne illness

Prevention

- Measures to prevent food poisoning and spoilage
  - Prevent incorporation
  - Prevent survival
- Temperature
- Radiation – UV, gamma rays
- Preservation – chemical, osmotic pressure, desiccation

Example of different temperatures and their effects on microbes.

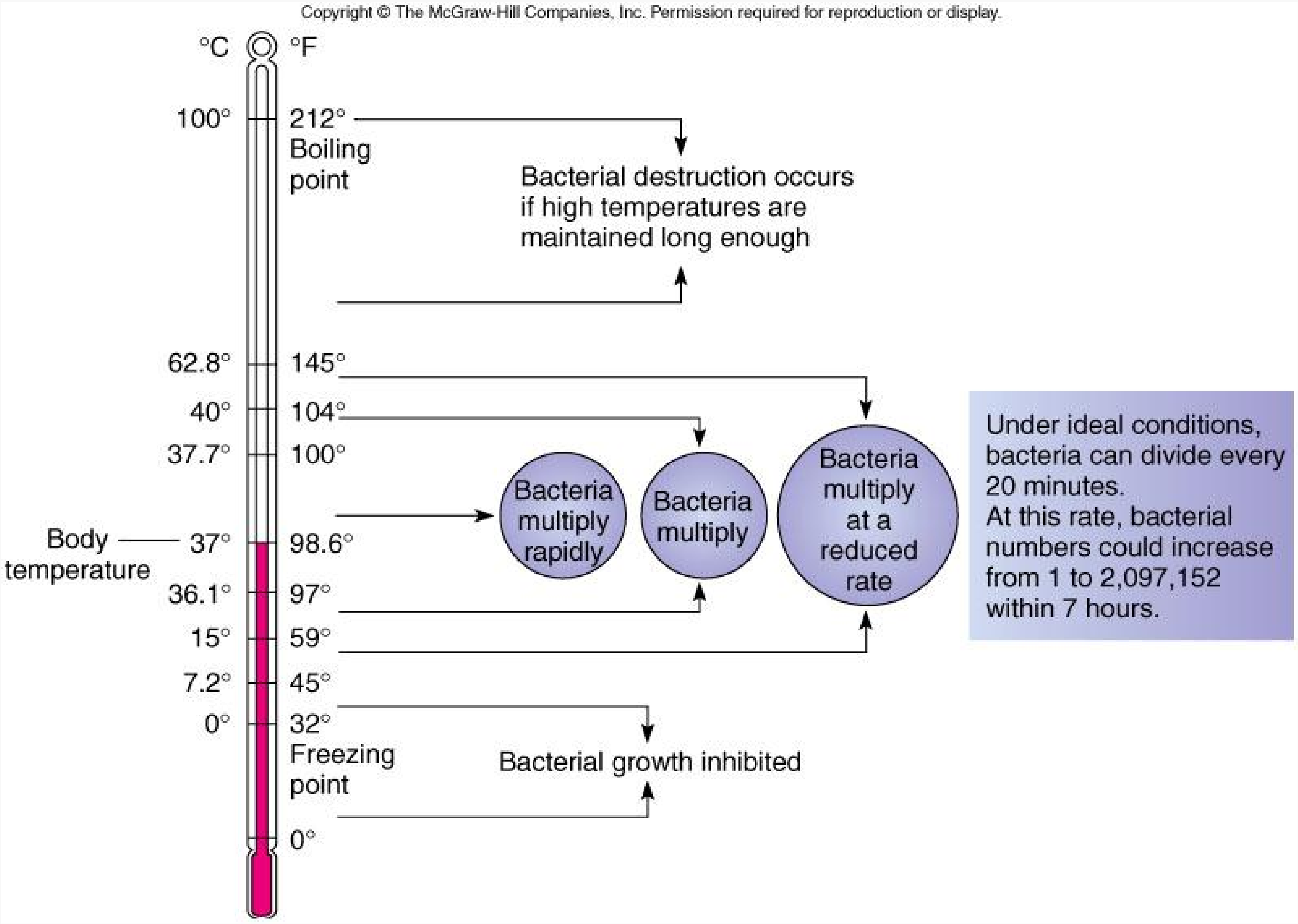


Fig. 24.28 Temperature favoring and inhibiting the growth Of microbes in food.

High temperature short-time pasteurization (HTST) is a method used to preserve milk.

Fig. 24.27 A modern flash pasteurizer

Examples of methods used to prevent food poisoning and food spoilage.

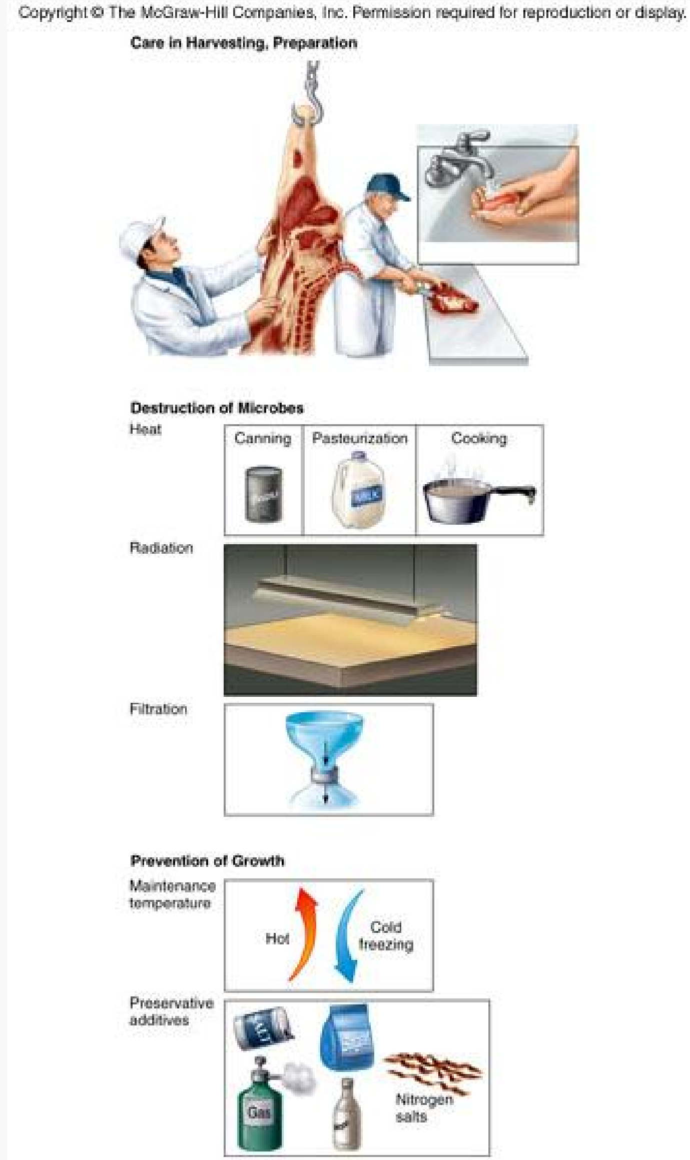


Fig. 24.26 The primary methods to prevent food poisoning And food spoilage.

Industrial microbiology

- Use of microbes to manufacture consumable materials
- Use of microbes to generate organic compounds
- Metabolites
- Controlled environment
- Primarily a fermentation process

Examples of industrial products produced by microbes.

TABLE 24.4 Industrial Products of Microorganisms

Chemical	Microbial Source	Substrate	Applications
Pharmaceuticals			
Bacitracin	*Bacillus subtilis*	Glucose	Antibiotic effective against gram-positive bacteria
Cephalosporins	*Cephalosporium*	Glucose	Antibacterial antibiotic, broad spectrum
Pencillins	*Penicillium chrysogenum*	Lactose	Antibacterial antibiotics, broad and narrow spectrum
Erythromycin	*Streptomyces*	Glucose	Antibacterial antibiotic, broad spectrum
Tetracycline	*Streptomyces*	Glucose	Antibacterial antibiotic, broad spectrum
Amphotericin B	*Streptomyces*	Glucose	Antifungal antibiotic
Vitamin B_{12}	*Pseudomonas*	Molasses	Dietary supplement
Riboflavin	*Asbya*	Glucose, corn oil	Animal feed supplement
Steroids (hydrocortisone)	*Rhizopus, Cunninghamella*	Deoxycholic acid, stigmasterol	Treatment of inflammation, allergy; hormone replacement therapy
Food Additives and Amino Acids			
Citric acid	*Aspergillus, Candida*	Molasses	Acidifier in soft drinks; used to set jam; candy additive; fish preservative; retards discoloration of crabmeat; delays browning of sliced peaches
Lactic acid	*Lactobacillus, Bacillus*	Whey, corncobs, cottonseed; from maltose, glucose, sucrose	Acidifier of jams, jellies, candies, soft drinks, pickling brine, baking powders
Xanthan	*Xanthomonas*	Glucose medium	Food stabilizer; not digested by humans
Acetic acid	*Acetobacter*	Any ethylene source, ethanol	Food acidifer; used in industrial processes
Glutamic acid	*Corynebacterium, Arthrobacter, Brevibacterium*	Molasses, starch source	Flavor enhancer monosodium glutamate (MSG)
Lysine	*Corynebacterium*	Casein	Dietary supplement for cereals
Miscellaneous			
Ethanol	*Saccharomyces*	Beet, cane, grains, wood, wastes	Additive to gasoline (gasohol)
Acetone	*Clostridium*	Molasses, starch	Solvent for lacquers, resins, rubber, fat, oil
Butanol	*Clostridium*	Molasses, starch	Added to lacquer, rayon, detergent, brake fluid
Gluconic acid	*Aspergillus, Gluconobacter*	Corn steep, any glucose source	Baking powder, glass-bottle washing agent, rust remover, cement mix, pharmaceuticals
Glycerol	Yeast	By-product of alcohol fermentation	Explosive (nitroglycerine)
Dextran	*Klebsiella, Acetobacter, Leuconostoc*	Glucose, molasses, sucrose	Polymer of glucose used as adsorbents, blood expanders, and in burn treatment; a plasma extender; used to stabilize ice cream, sugary syrup, candies
Thuricide insecticide	*Bacillus thuringiensis*	Molasses, starch	Used in biocontrol of caterpillars, moths, loopers, and hornworm plant pests

Table 24.4 Industrial products of microorganisms

Examples of industrial enzymes produced by microbes.

TABLE 24.5 Industrial Enzymes and Their Uses

Enzyme	Source	Application
Amylase	*Aspergillus, Bacillus, Rhizopus*	Flour supplement, desizing textiles, mash preparation, syrup manufacture, digestive aid, precooked foods, spot remover in dry cleaning
Catalase	*Micrococcus, Aspergillus*	To prevent oxidation of foods; used in cheese production, cake baking, irradiated foods
Cellulase	*Aspergillus, Trichoderma*	Denim finishing ("stone-washing"), digestive aid, increase digestibility of animal feed, degradation of wood or wood by-products
Glucose oxidase	*Aspergillus*	Removal of glucose or oxygen that can decolorize or alter flavor in food preparations as in dried egg products; glucose determination in clinical diagnosis
Hyaluronidase	Various bacteria	Medical use in wound cleansing, preventing surgical adhesions
Keratinase	*Streptomyces*	Hair removal from hides in leather preparation
Lipase	*Rhizopus*	Digestive aid and to develop flavors in cheese and milk products
Pectinase	*Aspergillus, Sclerotina*	Clarifies wine, vinegar, syrups, and fruit juices by degrading pectin, a gelatinous substance; used in concentrating coffee
Penicillinase	*Bacillus*	Removal of penicillin in research
Proteases	*Aspergillus, Bacillus, Streptomyces*	To clear and flavor rice wines, process animal feed, remove gelatin from photographic film, recover silver, tenderize meat, unravel silkworm cocoon, remove spots
Rennet	*Mucor*	To curdle milk in cheese making
Streptokinase	*Streptococcus*	Medical use in clot digestion, as a blood thinner
Streptodornase	*Streptococcus*	Promotes healing by removing debris from wounds and burns

Table 24.5 Industrial enzymes and their uses.

Industrial processes harvest primary metabolites from the log phase, and secondary metabolites from the stationary phase.

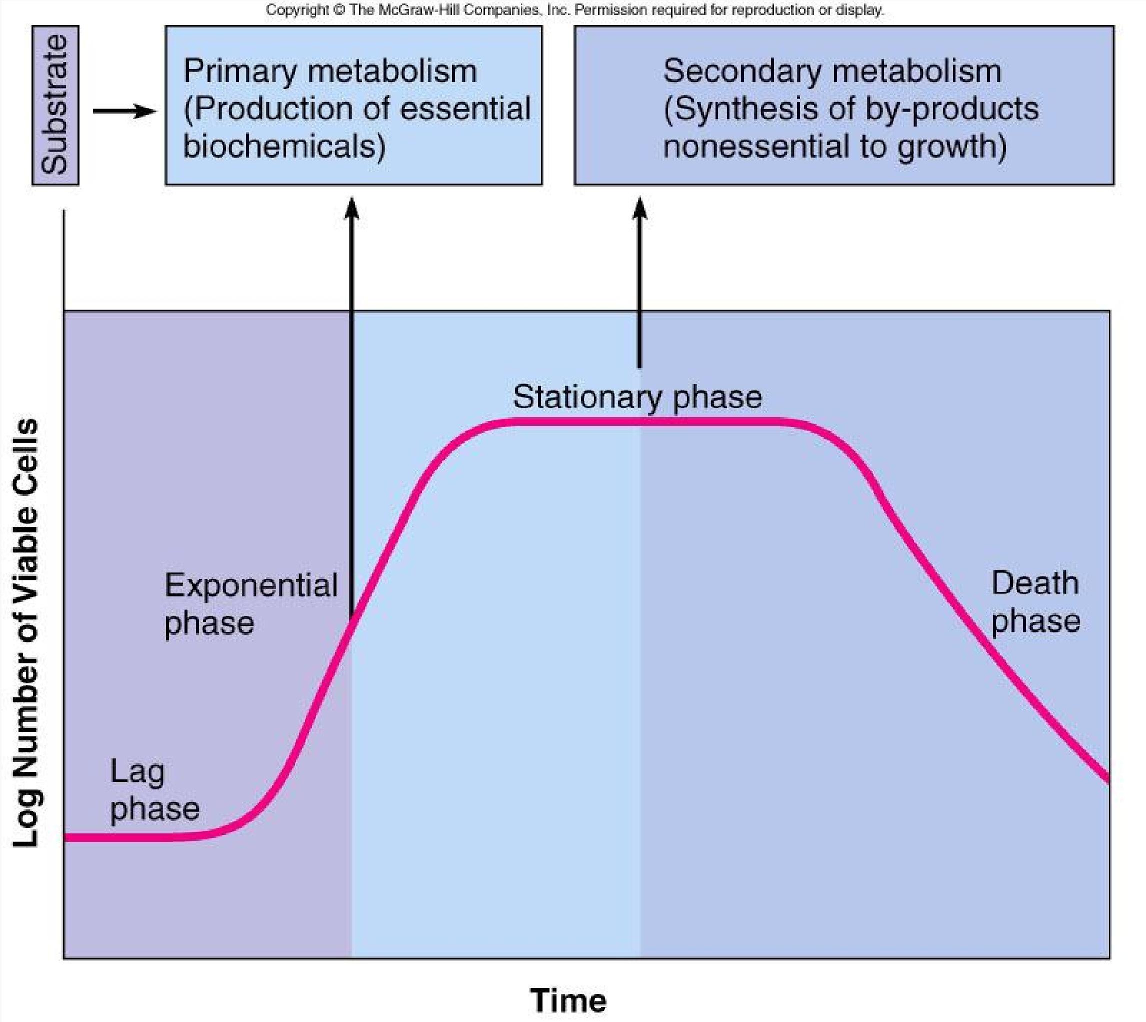


Fig. 24.29 The origins of primary and secondary microbial Metabolites harvested by industrial processes.

Large cell culture vessels are used to mass-produce pharmaceutical products.

Fig. 24.30 A cell culture vessel used to mass-produce Pharamaceuticals.

An example of an industrial fermentor used for mass culture of microorganisms.

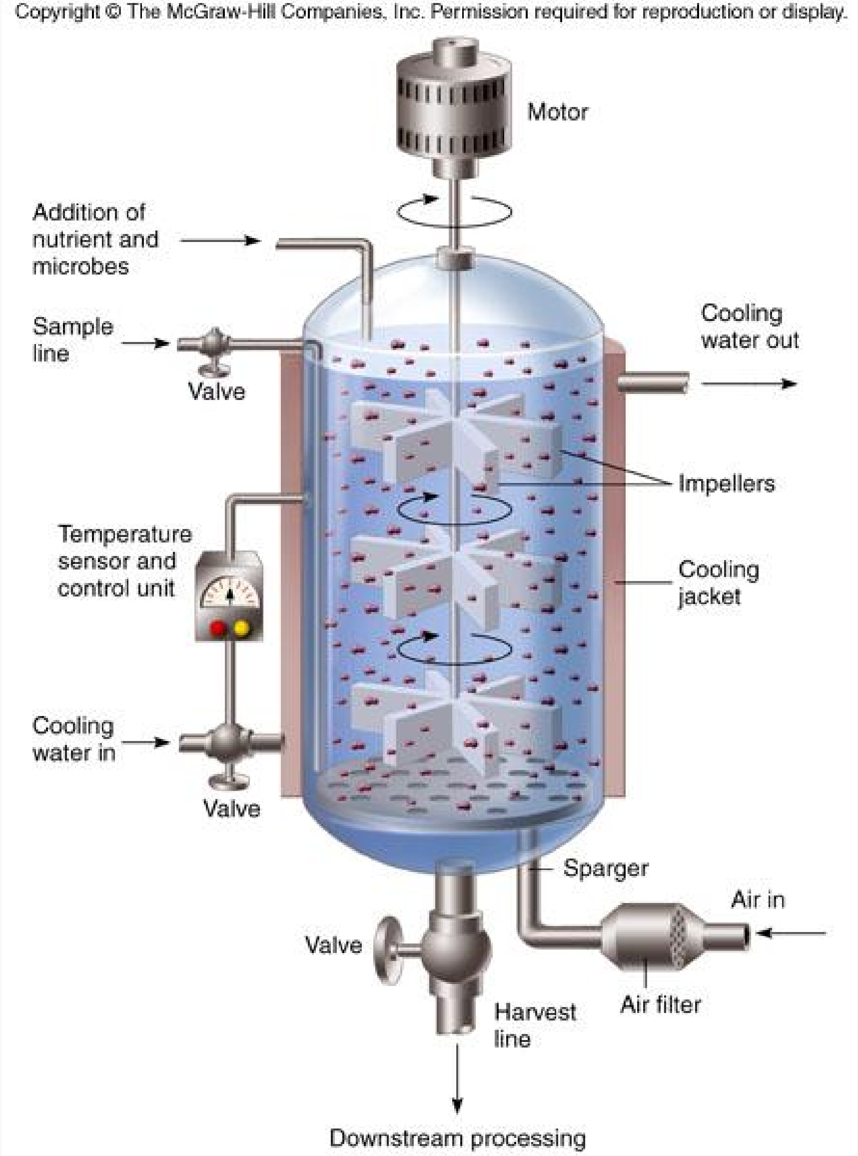


Fig. 24.31 A schematic diagram of an industrial fermentor

The general steps associated with a fermentor, and the mass-production of organic substances.

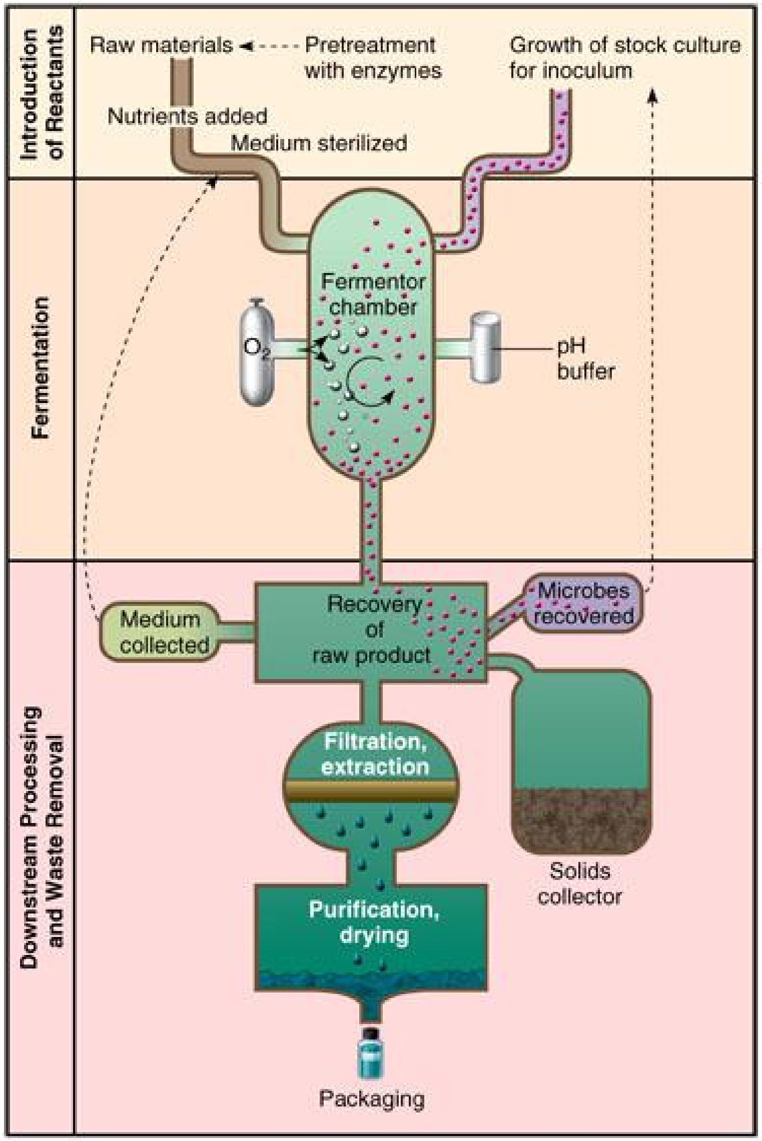


Fig. 24.32 The general layout of a fermentation plant